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Direct imaging of primary atomisation in the near-nozzle region of diesel sprays

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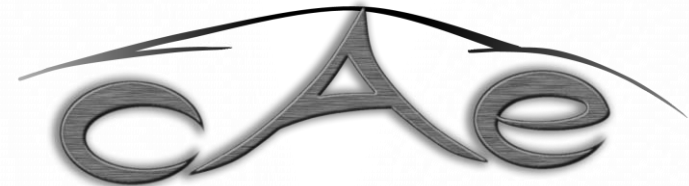
R. Pearson, M. Gold

BP Global Fuels Technology

University of Nottingham, 17th September 2014

EPSRC

Pioneering research
and skills





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- High-speed video and shadowgraphic microscopy
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Introduction

- The liquid fuel is injected at high velocity into a combustion chamber
- It atomizes into small droplets
- The atomized fuel vaporizes and mixes with high-temperature air
- Combustion occurs after vaporized fuel mixes with air

- Mixing and evaporation occurs at microscopic scales
- Initial stage of spray formation influences combustion process
- There is a need to study spray at macroscopic levels

Objectives

- *To study morphology of fuel droplets during the injection process at microscopic scales in near nozzle region to aid model correlation*

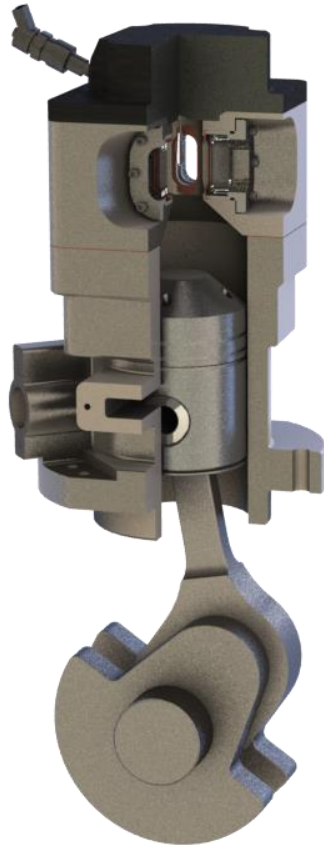




Evaporative test conditions

➤ Rapid Compression Machine (RCM) is:

A single cylinder Ricardo Proteus two-stroke test engine



- Bore: 135 mm
- Stroke: 150 mm
- Displacement: 2.2 l
- RPM: 500
- Quiescent air motion at TDC
- P_{inj} : 30-200 MPa
- ICP: up to 12 MPa
- TDC temperatures 540-850 K



Evaporative test conditions (cont.)

Target operating conditions

| O ₂ | In-cylinder Temp, K | In-cylinder Density, kg/m ³ | ICP, bar | Inj. Pressure, bar | Fuel | Inj. Duration Based on trigger, ms |
|----------------|---------------------|--|----------|--------------------|------------|------------------------------------|
| 21% | 700 | 22.8 | 48 | 500, 1000, 1500 | n-dodecane | 1.5 |

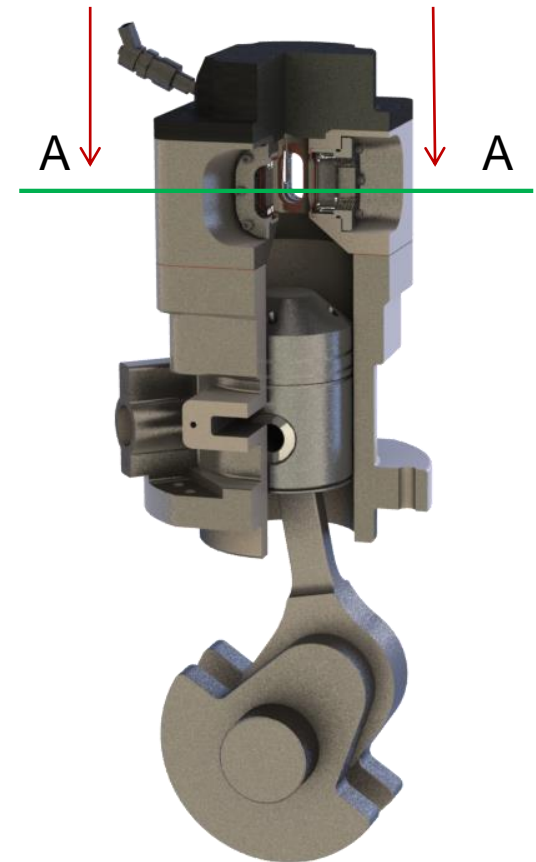
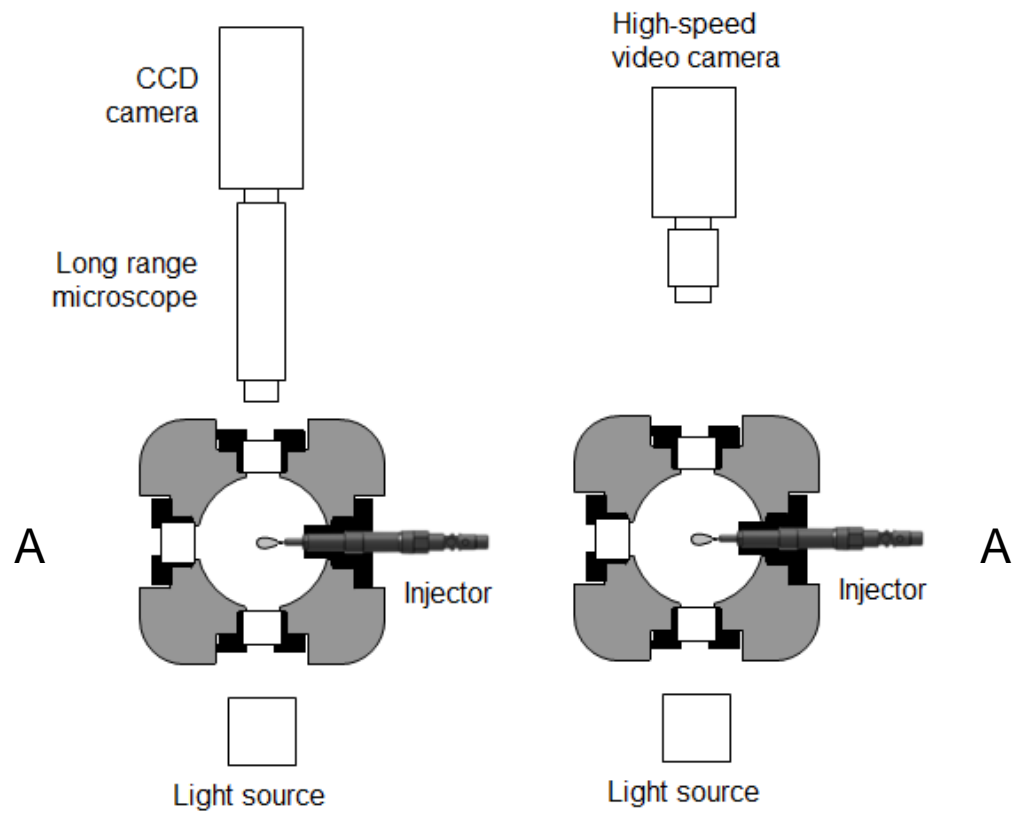
Specifications for the injector (IFPEN 201.02 ECN spray A)

| Description | Value |
|--------------------------------|--|
| Type | Bosh solenoid-actuated, generation 2.4 |
| Nominal nozzle outlet diameter | 0.090 mm |
| Nozzle K factor* | 1.5 |
| Nozzle shaping | Hydro-erosion |
| Mini-sac volume | 0.2 mm ³ |
| Number of holes | 1 (single hole) |
| Orifice orientation | Axial (0° full included angle) |





High-speed video and microscopy





High-speed video and microscopy system

Long-distance microscope



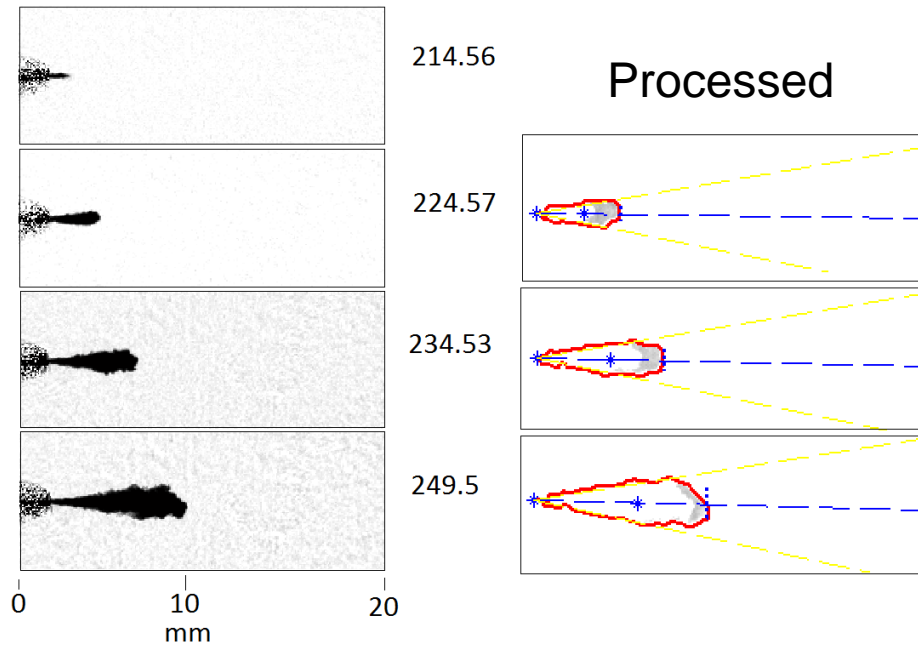
CAVILUX Smart 640 nm
pulsed diode laser light source



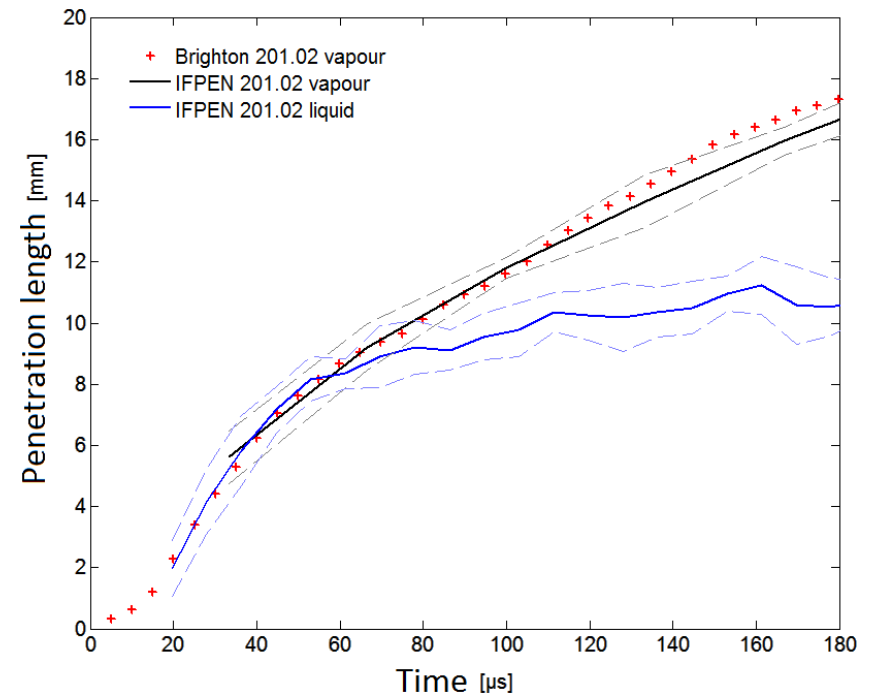
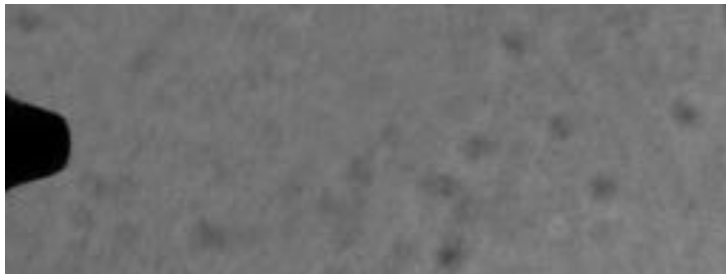
Phantom V710 high-speed camera
80-200 mm Nikon AF Nikkor



Start of injection (HSV)



Motored @ ICP 4.5 MPa



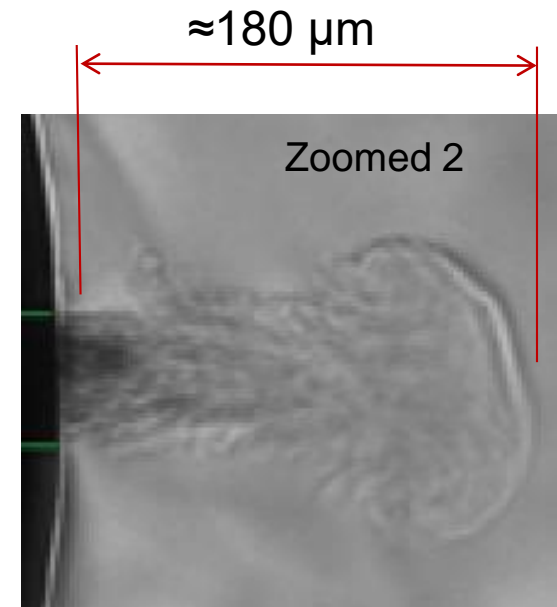
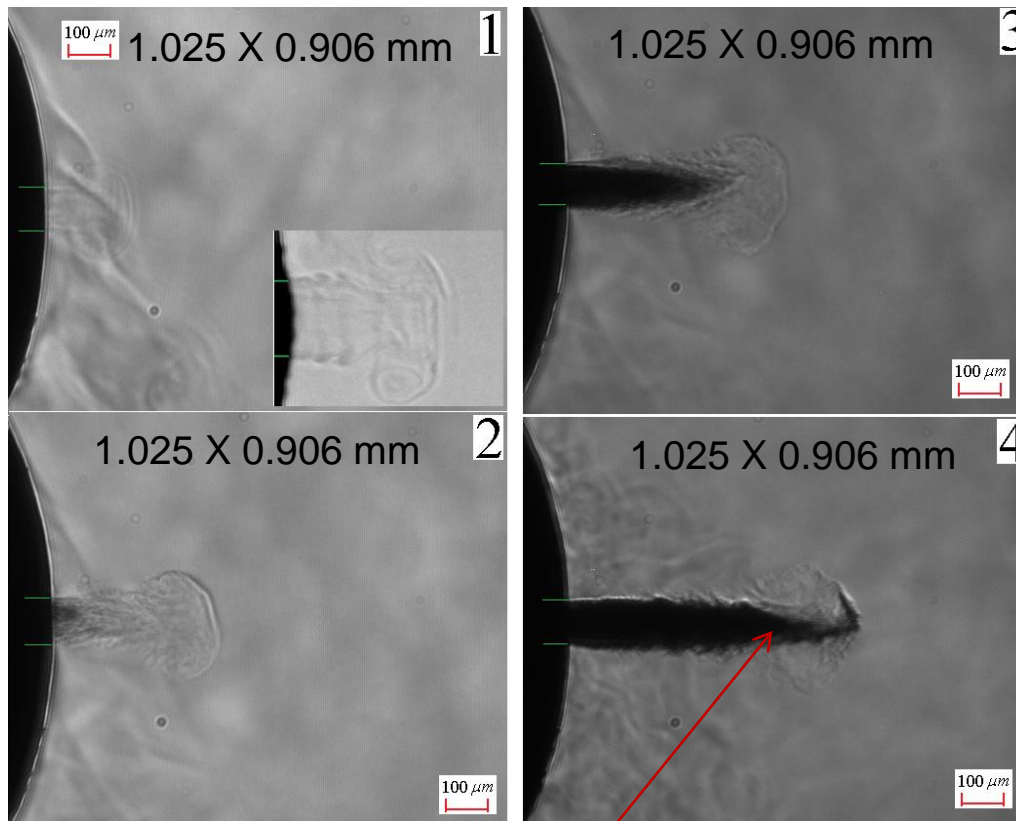
- Dashed line is standard deviation
- IFPEN injector 201.02 at 900K 22.8 kg/m³
- Good correspondence with liquid and vapour IFPEN data



Start of injection (Microscopy)

Liquid-vapour mixture exiting the nozzle hole for 0.295 ms ASOI

$P_{inj} = 150 \text{ MPa}$, $ICP = 4.8 \text{ MPa}$



Fuel jet eventually pierces through this vapour cap



Start of injection (Microscopy)

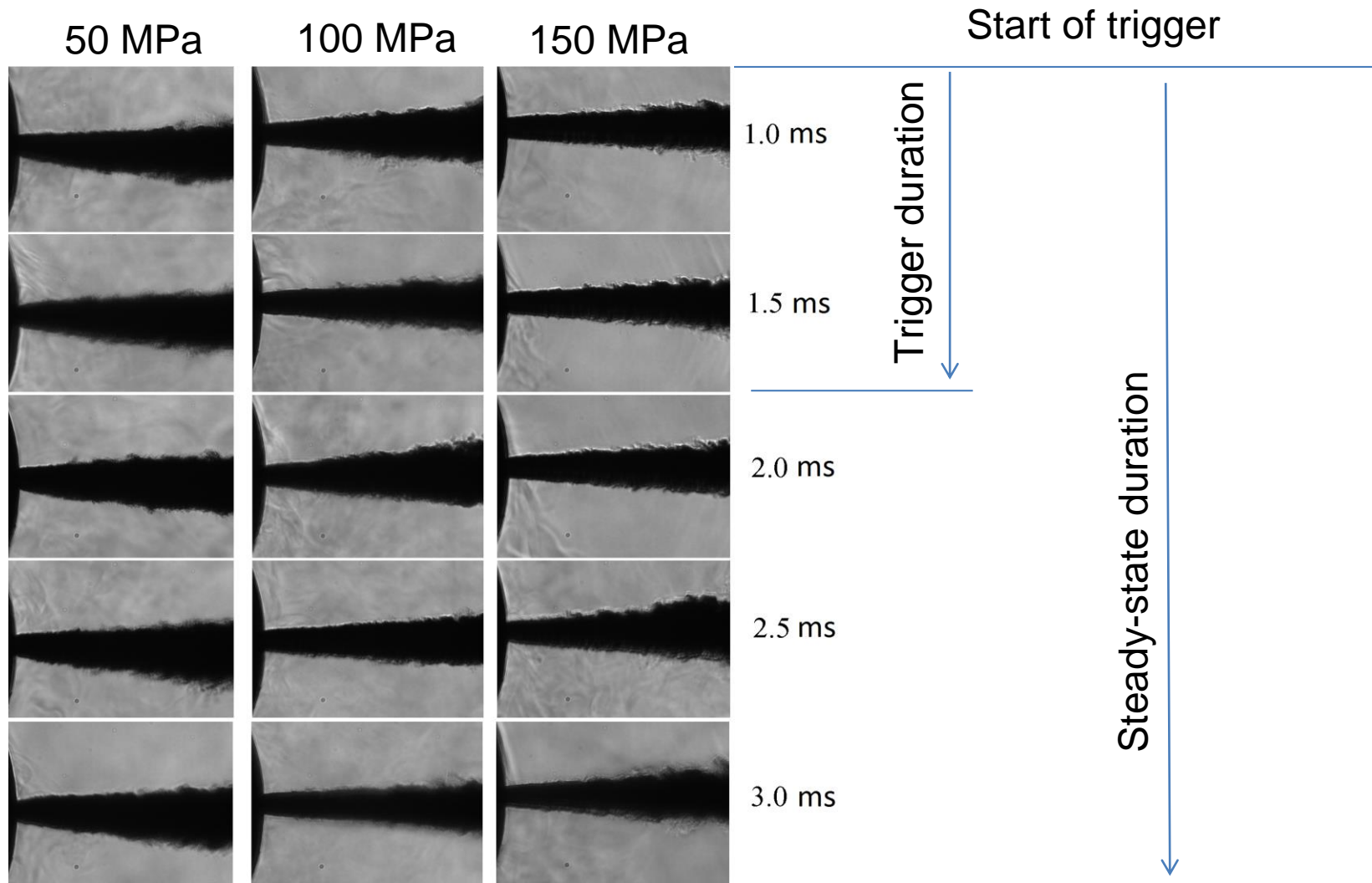
Vapour pre-jet was also reported for other injectors e.g.
Delphi 1.3 7-hole, 135 μ m VCO and fuel (ULSD)

The vapour pre-jet can be caused by:

- Expansion of cavitation pockets after previous injection
- Ingestion of in-cylinder gases after previous injection
- Heating and evaporation of fuel inside orifice
- Can be ignited (if it is fuel vapour)
- Modelling may need to account for in-nozzle fluid properties

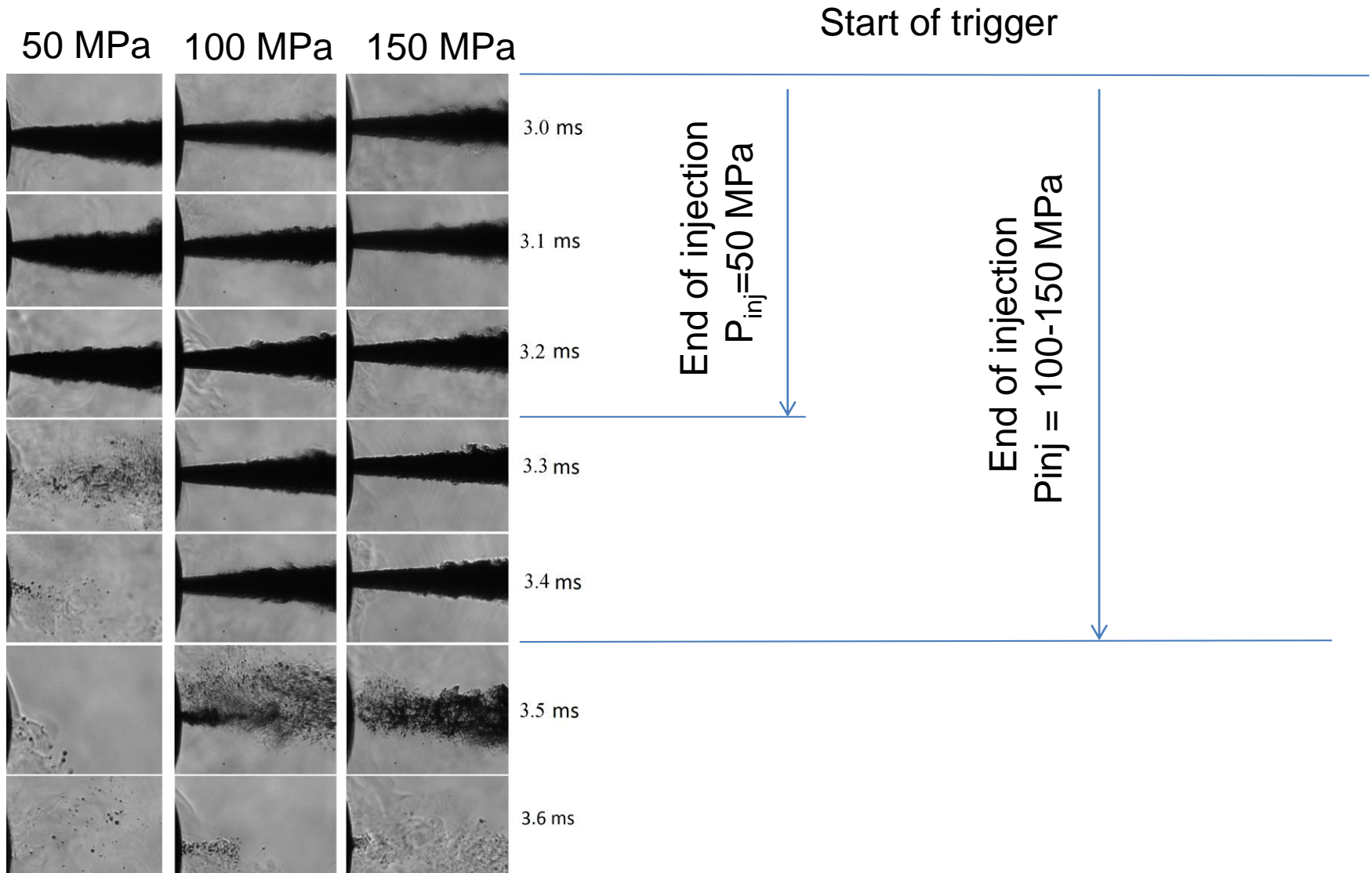


Steady-state (1.0-3.0 ms)





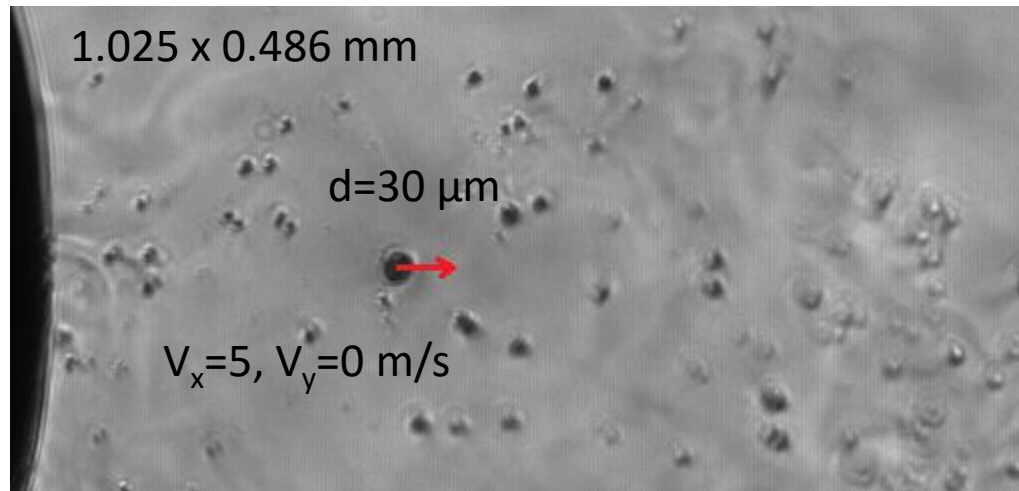
End of injection (3.0-3.6 ms)





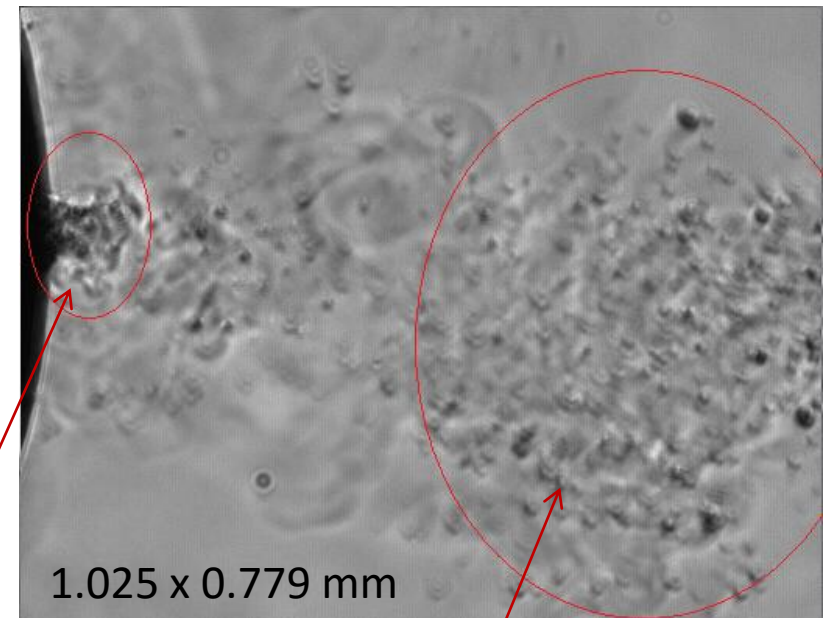
End of injection in ECN injector

$P_{inj} = 100$ MPa, 3.7 ms ASOI



- Large 'slow' droplets
- Micro-injection events
- Random droplet trajectory
- Spherical droplets

Micro-injection events after EOI
 $P_{inj} = 150$ MPa for 3.6 ms ASOI



Start of micro-injection event

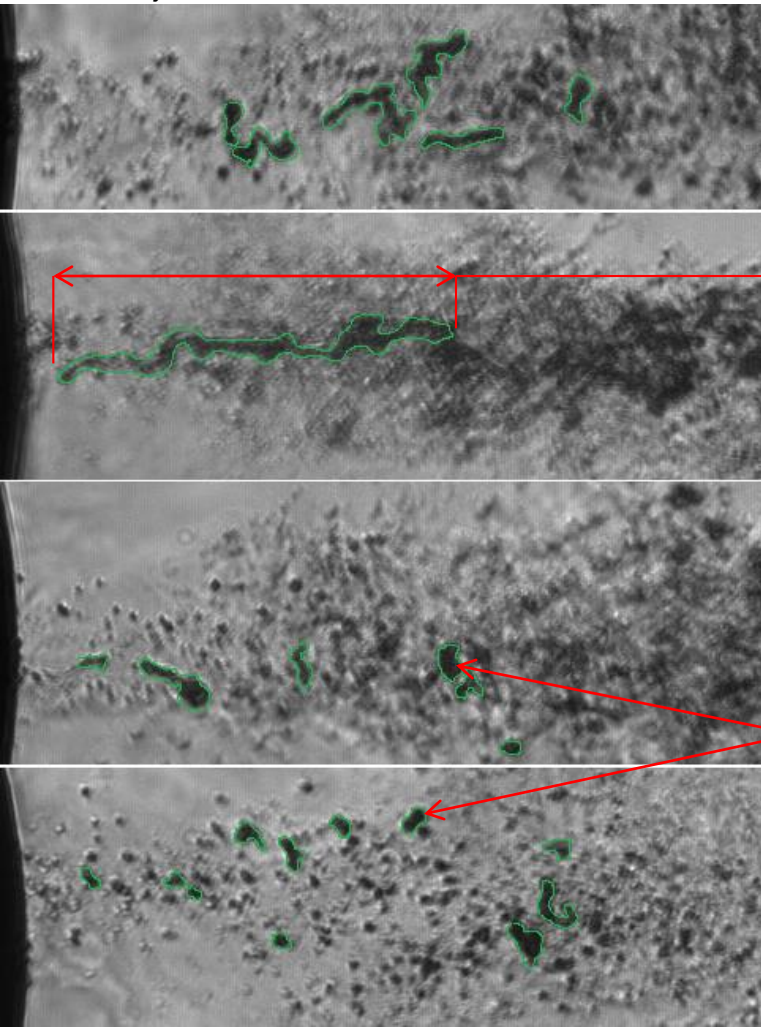
Droplets from 'main end of injection'

Secondary micro-injection events in the ECN injector could be caused by:
The needle bouncing from the seat or by expansion of the fluid in the sac



End of injection (cont.)

$P_{inj} = 50 \text{ MPa}$, 3.3 ms ASOI



- Large ligaments as well as highly deformed droplets are observed for low P_{inj}
- Hard to process in order to extract statistics

Long structures ($\sim 420 \mu\text{m}$)

- Long irregular ligaments present significant modelling challenges for
 - a) initialisation of emerging fluid
 - b) modelling of subsequent evaporation and transport

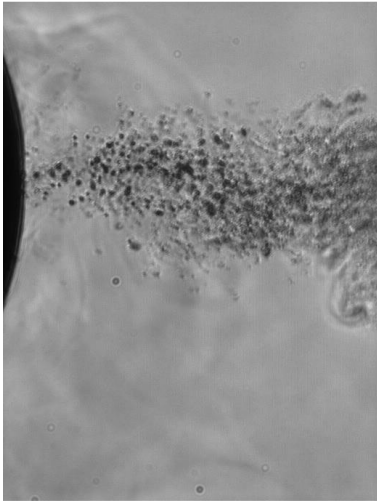
Non-spherical droplets

3D shape reconstruction, is needed in order to estimate the droplet surface area and volume

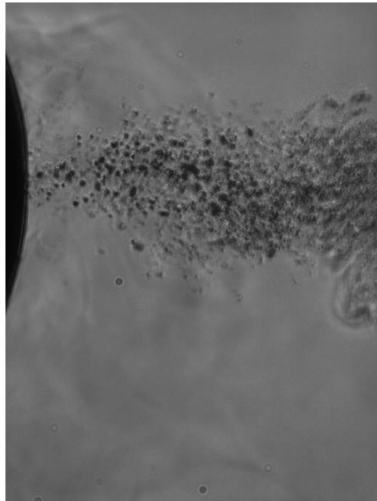


End of injection (cont.)

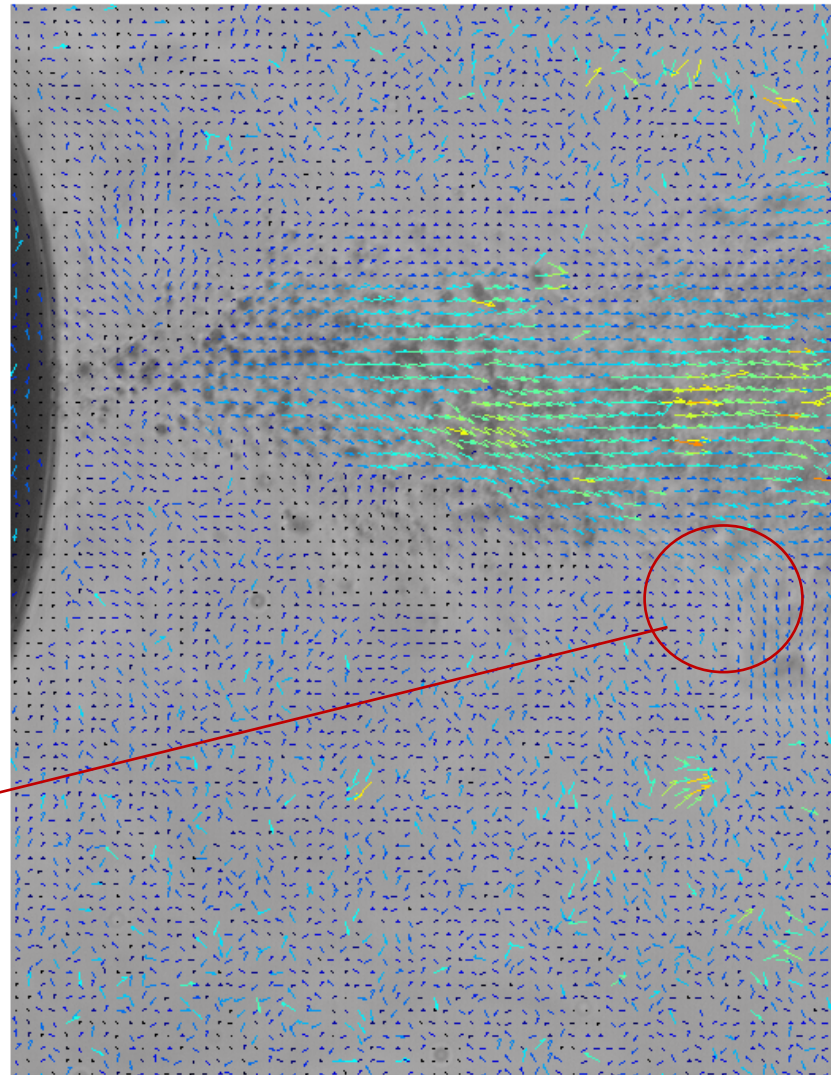
Frame 1



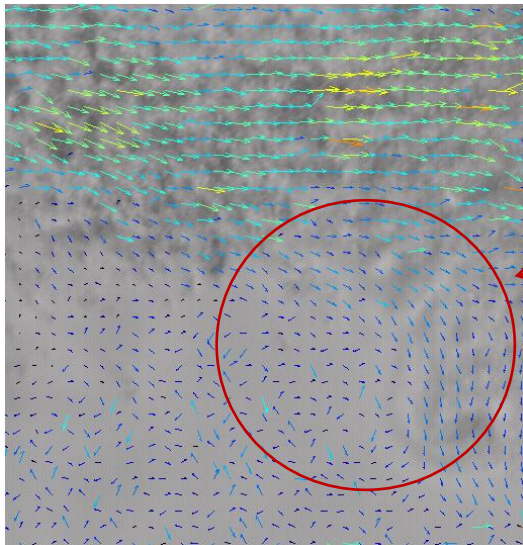
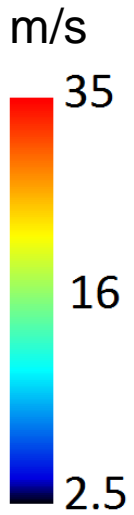
Frame 2



$P_{inj}=50$ MPa 3.3 ms ASOI



Velocity vectors





Conclusions

- Long injection process (compared to trigger duration) due to single-hole design
- Vapour pre-jet for a range of pressures of circa constant length was observed
- Secondary injection even due to possible needle bouncing or fuel expansion in sac
- Large droplets and long ligaments with low velocity for low injection pressures
- Quantitative velocity field of droplets or gas phase can be obtained



Acknowledgments

Equipment

EPSRC Engineering Instrument Pool

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BP Global Fuels Technology

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